On the NUMBER *of the* PRIMITIVE COLORIFIC RAYS *in* SOLAR LIGHT. *By the Rev.* MATTHEW YOUNG, *D. D. S. F. T. C. D. & M. R. I. A.*

Read April 7th, 1798.

THE opinion that there are but three primitive colours has been maintained by M du Fay, and after him by Father Caſtell. See Montucla, Vol. I p. 630.; but they and all others who hold the ſame doctrine, defend it merely on the principles of a painter, who ſhews how with theſe three colours on his pallet, he can compound all others; for with red and yellow he can form an orange colour; with blue and yellow he forms green; and with blue and red he forms indigo and violet; and thus having compounded the ſeven priſmatic colours, it is manifeſt that all other colours, with their different gradations, can be formed from them likewiſe. But this *pharmaceutical* argument is by no means ſufficient to ſatisfy us as to the real compoſition of ſolar light.

" LIGHT, in refracting, is decompoſed into ſeven rays, red, " orange, yellow, green, blue, indigo and violet. It has been " ſuppoſed,"

" ſuppoſed," ſay Fourcroy, " that three of theſe colours, the " red, yellow and blue, were ſimple; and that the other four " were formed each of its two neighbours; that is, the orange " from the red and yellow, the green from the yellow and blue, " the indigo from the blue and violet, and the violet from the " red and indigo. But this ſuppoſition has never been proved." See his Philoſophy of Chem. ch. 1. § 3. Beſides that this is a mere hypotheſis, unſupported by any fact, as Fourcroy obſerves, we remark, that it is in itſelf inadequate; 1ſt, becauſe in the ſolar ſpectrum, the red and indigo are not *neighbouring* colours, but are almoſt at the greateſt poſſible diſtance from each other. 2dly, According to this hypotheſis, indigo is compoſed of blue and violet; but violet is compoſed of red and indigo; indigo therefore is compoſed of red, blue and indigo, that is, indigo itſelf is one of its own eſſential ingredients, which is abſurd.

The experiments of the priſm ſeem to eſtabliſh, in a very clear manner, the exiſtence of ſeven original and uncompounded colours; and though green, for inſtance, may be compounded of blue and yellow, yet it does not directly follow from thence, that it always is ſo actually compounded. Accordingly Newton tells us, that green may be exhibited in two different ways, either by primitive, green-making rays, which are ſimple and not reſolvable by any reflection or refraction into different rays; or by a compoſition of blue and yellow rays, which are differently refrangible, and which therefore after their union, may again be ſepa-

rated

rated by refraction, and exhibit their proper colours of blue and yellow.

On this doctrine of the two-fold generation of green, we may in the firſt place remark, that the antient, received axiom "Deus "nil agit fuſtra" ought not to be too haſtily abandoned, as it muſt appear to be, if this doctrine be maintained: for if green may be produced by blue and yellow, then blue and yellow being already exiſtent, green is a conſequence; and therefore peculiar rays formed for the production of green are ſuperfluous. Though I acknowledge, that this maxim is not ſo cogent or ſelf-evident, as to preclude all objection, yet ſince the general obſervation of nature ſeems to ſhew, that this waſte of power or multiplicity of means is not adopted by the Supreme Artiſt, it certainly ſeems juſtly entitled to our attention, at leaſt ſo far as this, that we ſhould be careful in ſhewing, that we are led to theſe different cauſes of the ſame effect, by a legitimate and cautious analyſis.

In defence of the doctrine of three primitive colours only, F. Caſtelli contents himſelf with ſaying, that the colours of the priſm are immaterial, accidental, artificial, and therefore unworthy the regard of a philoſopher; whereas the colours of painters are ſubſtantial, natural, palpable. From them, of conſequence, the theory of chromatics ſhould be deduced; but they

tell us, that there are but three parent colours, which give birth to all others.

In reply to this we need only obſerve, that Sir I Newton has proved, that the colours of natural bodies depend on the colorific qualities of the rays of light; and therefore that our theory of colours muſt be derived from an enquiry into the conſtitution of ſolar light, for according to that conſtitution the colours of bodies will vary: and he farther ſhews, that if ſolar light conſiſted of but one ſort of rays, all bodies in the world would be of the ſame colour. However true therefore F. Caſtelli's theory may be, the manner in which he deduces it from phænomena is unqueſtionably falſe.

I ſhall therefore proceed to enquire ſcrupulouſly into the compoſition of the ſolar ſpectrum, from which, without doubt, the true doctrine of the origin of colours is to be derived.

If the ſolar-light conſiſted of ſeven primitive, homogeneal coloured rays, and that theſe homogeneal rays were equally refrangible, the ſpectrum would conſiſt of ſeven circles of different colours, ſince the homogeneal rays of each colour would paint a circular image of the ſun. But it is manifeſt, that ſeven circles could not compoſe an oblong ſpectrum, with rectilineal ſides. Therefore the rays of the ſame denomination of colour muſt be differently refrangible. Which is alſo made ſtill farther evident

evident by obſervation of the ſpectrum, ſince in it we perceive, that the priſmatic colours are diffuſed over ſpaces, which are, on the ſides, terminated by right lines, and therefore the centers of the circles of the ſame denomination of colour are diffuſed over lines equal to theſe ſegments of the rectilineal ſides of the ſpectrum. Newton has ſhewn, prop. 4. B. 1. Optics, how to ſeparate from one another theheterogeneous rays of compound light, by diminiſhing the breadth of the ſpectrum, its length remaining unchanged; and when the length of the ſpectrum is to its breadth, as 72 to 1, the light of the image is ſeventy-one times leſs compound than the ſun's direct light. In the middle of a black paper he made a round hole, about a fifth or a ſixth part of an inch in diameter, upon which he cauſed this ſpectrum ſo to fall, that ſome part of the light might paſs through the hole of the paper; this tranſmitted part of the light he refracted with a priſm placed behind the paper, and letting the light fall perpendicularly upon a white paper, he found that the ſpectrum formed by it was perfectly circular. Hence, therefore, it follows, that the equally refrangible rays occupy a ſpace on the rectilineal ſides of the ſpectrum equal at leaſt to the fifth or ſixth part of an inch; that is, the rays of the ſame colour are differently refrangible.

THE different quantity of the homogeneous rays of different colours will not account for the different ſpaces they occupy in the ſpectrum; for this difference in quantity would affect only the intenſity of the colour, not the magnitude of the ſpace which it

would occupy. All the red light therefore is not homogeneous; but conſiſts of rays of innumerable, different degrees of refrangibility; and ſo of the other colours.

Now ſince the rays which are of the ſame denomination of colour are differently refrangible, they will either form oblong ſpectrums detached from each other; or they will in part lap over, and fall on each other. The former poſition is manifeſtly falſe: therefore the original priſmatic colours will partly lap over and fall on each other, and therefore neceſſarily generate the intermediate colours. And ſo Sir I. Newton obſerves, where he ſays, that the original, priſmatic colours will not be diſturbed by the intermixture of the conterminous rays, which are intermixed together. This overlapping however, which Newton ſpeaks of, ariſes only from the ſun's having a ſenſible diameter, and does not neceſſarily imply an equal refrangibility in any differently coloured rays. If there be but three original priſmatic colours, red, yellow and blue, and that the red and yellow lap over, ſo as that there ſhall be a certain ſpace in the ſides of the ſpectrum equally occupied by yellow and red circles, then will theſe circles by their intermixture compound an orange colour; and this colour as to refrangibility will be homogeneous, becauſe the coincident rays of different colours are equally refrangible. In like manner green may be compounded by the mixture of blue and yellow circles, equally refrangible. Now this is ſimple, and conformable to the other phænomena of the ſpectrum; for if rays of the

the ſame denomination of colour be differently refrangible, it is not unreaſonable to ſuppoſe, that rays of a different denomination of colour may be equally refrangible; and therefore ſince the red rays are unequally refrangible, and likewiſe the yellow, there is nothing incongruous in ſuppoſing that ſome of the leſs refrangible of the yellow may be equally refrangible with ſome of the more refrangible of the red; and if ſo, they will conſequently be intermixed with them: and the ſame may be ſaid of the green. This hypotheſis likewiſe receives conſiderable ſtrength from this conſideration, that the orange, green, indigo and violet occupy thoſe places which they ought to do, in caſe there were but three primitive colours, red, yellow and blue: thus the orange lies between the red and yellow, becauſe it is formed by ſome of the extreme rays of red and yellow, which are equally refrangible; in like manner the green lies between the blue and yellow, becauſe it is formed by the mixture of blue and yellow. The indigo and violet muſt alſo occupy the extreme part of the ſpectrum, where the moſt refrangible red and blue rays are united, and gradually becoming more and more dilute, fade away, and at length entirely vaniſh. But if the orange, green, indigo and violet be primitive colours, there is no apparent reaſon why they ſhould have had ſuch degrees of refrangibility aſſigned them, as that they ſhould occupy the places they do, rather than any other.

Moreover, if theſe three colours red, yellow and blue be the primitive colours, they cannot themſelves be generated; and accordingly

cordingly we find, that yellow cannot be generated by the mixture of the adjacent priſmatic colours orange and green; and the reaſon of this is evident, becauſe orange is compounded of red and yellow; and green is compounded of yellow and blue; but red and blue compoſe purple; which added to the yellow will generate a new compound colour, viz. a ſickly green, differing manifeſtly from yellow, the colour which ought to reſult according to the analogy of the other primitive colours, in which the extremes, by their mixture, generate that which is intermediate. In the ſame manner, blue cannot be generated by the mixture of green and indigo, becauſe green is compoſed of yellow and blue, and indigo of blue and violet; therefore the reſulting colour is compoſed of blue, yellow and violet; but yellow and violet do not compoſe blue, therefore neither will blue, yellow and violet compoſe a blue colour. Now if orange and green be primitive colours, in the ſame manner as red, yellow and blue, we can aſſign no reaſon why blue ſhould not be generated by the mixture of the adjacent colours, as well as green and orange. But it is a received principle, that an hypotheſis ſhould ſolve all the phænomena; of the two hypotheſes therefore, namely, that there are ſeven primitive colours, differently refrangible; or that there are but three, ſome of which, of each ſpecies, are equally refrangible; the latter alone ſolves all the phænomena of the ſolar ſpectrum, and therefore is to be preferred.

If it be ſaid, that thoſe rays which are equally refrangible muſt excite the ſame ſenſation on the retina, becauſe they muſt have

have the ſame momentum; it is replied, 1ſt, That it has not yet been proved, that the ſenſation of different colours depends on the different momentum of the rays. 2dly, The rays may have different momentums, and yet be equally refrangible; for ſince refraction is ſuppoſed to depend on the attractive force of the denſer medium, we muſt ſuppoſe it analogous to the attractive force of gravity, which is proportional to the quantity of matter; and therefore the greater or leſs quantity of matter in a particle of light would produce no alteration in its refraction. Neither can the different refrangibility depend on the different velocity of the rays; becauſe the difference of refrangibility of the red and violet rays is much greater in flint glaſs than in crown glaſs; and this would require a proportionably greater difference in the original velocities, which cannot be. And this ſame argument holds equally againſt the former hypotheſis, that the difference of refrangibility depends on the different magnitude or denſity of the particles of light. 3dly, Refraction ſeems to ariſe from a ſpecies of elective attraction, ſince different mediums which act on the mean rays equally, act on the extreme rays unequally: hence rays of the ſame quantity of matter and velocity, and therefore of the ſame momentum, may be diverſely refracted; and rays of different momentums equally refracted.

Nor is it to be wondered at that the rays of light ſhould be differently refrangible, independent of any regard to their momentum, when we conſider, that the different coloured rays appear

pear to be combined with combuſtible bodies, with different degrees of attractive force. For in combuſtion we find, that different bodies are diſpoſed to part with different rays with greater facility; but when the combuſtion is ſufficiently rapid, they part with all the different coloured rays together, and the flame is therefore white; and this is what is called a white heat. Dr. Fordyce in the Phil. Tranſ. for 1776, tells us, that when the heated ſubſtances are colourleſs, they firſt emit a red light; then a red mixed with yellow, and laſtly, with a great degree of heat, a pure white. All this is wonderfully conformable to the refraction of light by tranſparent ſubſtances, which refract and therefore attract the red light leſs, and conſequently in combuſtion part with it more eaſily. On the other hand I know it is generally believed, that the light in combuſtion proceeds from the air, but this circumſtance of the different colour of the light in different caſes, ſeems to overturn this opinion; for if vital air were oxygen diſſolved in caloric and light, then the oxygen being abſorbed by the burning body, the light extricated would in all caſes be of the ſame nature, the greater or leſs rapidity of the combuſtion would only produce an extrication of a greater or leſs quantity of light, but could not produce any variation in its nature, it being neceſſarily the ſame in all caſes, to wit, that in which vital air is diſſolved. But the truth or falſhood of this reaſoning will not affect the validity of the poſition, that the refrangibility of the rays of light cannot depend on the different magnitude, denſity or velocity of the particles.

But though ſpeculation ſeems thus to render it probable that there are but three parent colours, our theory muſt ever remain unſatisfactory, unleſs it receives the ſanction of direct experiment. In this however there is no ſmall difficulty; for ſince the rays of light which compoſe any given individual point of the colours of orange, green, violet, and indigo are equally refrangible, they will be alſo equally reflexible; and therefore cannot be ſeparated either by refraction or reflection, ſo as to exhibit the different coloured rays of which they are compoſed. It ſeems therefore, that the only way remaining, by which we can experimentally aſcertain the compoſition of theſe colours, if they be indeed compound, is tranſmiſſion. For ſince tranſparent coloured bodies are ſuch merely by their letting paſs through them either ſolely, or more copiouſly, rays of a certain colour, and intercepting all others, ſuch tranſparent bodies, applied to compound colours, will aſcertain that compoſition, by extinguiſhing, in a great meaſure, all rays except ſuch as are ſo adapted to its conformation, as to paſs through it, and give it its peculiar denomination of colour.

In order to try the truth of the hypotheſis of ſeven colours by this teſt, I looked through a blue glaſs at the red end of the ſpectrum: now we are to conſider, that if that part of the ſpectrum was compoſed of red rays, and none other, the only effect of the blue glaſs would either be a total or partial ſuffocation of the red rays; and therefore that part of the ſpectrum, when looked at

through the glaſs, would either totally diſappear, or become a faint and diluted red. But, on experiment it appeared of a purple colour. The purple in this caſe could not be a primitive and original colour, as is manifeſt, becauſe it did not proceed from the purple part of the ſpectrum; we muſt therefore conclude, that it was a compound colour. But purple, when compound, is made up of blue and red, therefore it follows, that ſome blue rays did actually exiſt in the red part of the ſpectrum; which combined with the few, ſtraggling red rays which penetrated the blue glaſs, compoſed that purple colour, which the red extremity of the ſpectrum aſſumed, when viewed by the light tranſmitted through the blue medium.

To try, on the other hand, whether any red rays lay hid amongſt the blue, I proceeded in the ſame manner, and looking at the blueſt part of the ſpectrum through a red glaſs, it appeared of a purple colour; ſome red rays therefore are equally refrangible with the blue; and if the red extends as far as the blue, there is no reaſon why we may not ſuppoſe that it extends ſomewhat farther, ſo as to compound, with a diluted blue, the extreme colours of the ſpectrum, indigo and violet.

But it may be ſaid, that if blue rays exiſted amongſt the red, that part of the ſpectrum could not appear ſo extremely brilliant as it really does; but would put on a purpliſh appearance in the ſpectrum itſelf, even to the naked eye. In anſwer to this objection

we

we may obſerve, that the moſt intenſe and vivid, natural red bodies do, in fact, reflect a very great proportion of blue rays, becauſe they appear of a ſtrong blue colour when placed in the blue part of the ſpectrum; and therefore they reflect juſt as many when the direct, white ſolar light falls on them, in which all that blue is involved; though by the predominance of the red rays, they appear of that colour, without any viſible tincture of blue.

In order to determine whether the purple appearance of the red extremity of the ſpectrum, when viewed through a blue glaſs, was cauſed by any of the white ſolar light, which might perhaps be reflected from the air, or ſurrounding objects to the ſpectrum, and thus throw on that part ſuch a quantity of blue as might produce a ſenſible effect; I cauſed the middle and moſt intenſe part of the red to paſs through a hole in a blackened paper, and then fall on an optical ſcreen; by which I was ſure that I had as pure and uncompounded a red as could be deſired; which alſo underwent the uſual teſt of purity by ſubſequent refraction, without any change in the form of the ſpectrum; I then looked at the body which was illuminated with this red, through the ſame blue glaſs, and the effect was the ſame as before.

To try this doctrine of three parent colours ſtill farther, I conſidered, that if the orange were really compounded of the red and yellow rays, then by looking at the orange through a red glaſs,

the orange would in a great meaſure vaniſh, and the red would appear to extend much farther than in the original ſpectrum; becauſe the yellow rays being conſiderably obſtructed, the red would become more predominant; and that part of the ſpectrum, which before appeared orange, in conſequence of a certain mixture of yellow and red, would now, by the failure of ſo conſiderable a part of the yellow, loſe its orange appearance, and put on that of red: and, on experiment, I found the caſe to be ſo really in fact; for while an aſſiſtant looked at the ſpectrum through the red glaſs, I moved an obſtacle from the red towards the other end of the ſpectrum, deſiring him to ſtop me, when the obſtacle ſhould arrive at the confines of red and orange; but when he did ſo, the obſtacle had attained the middle of the orange, or rather had paſſed beyond it. Now if the orange were really a primitive colour, I ſhould ſuppoſe, that when looked at through the red glaſs, it would either appear diluted, without any change of dimenſions; or that if the weak part of the orange, next the red, ſhould vaniſh, by the obſtruction of the glaſs, a dark interval would appear between the orange and the red; in neither caſe can we account for the apparent extenſion of the red into the region of the orange; nor by any other hypotheſis, as appears to me, than that ſome of the red rays are equally refrangible with ſome of the orange.

THERE is another argument derived from the ocular ſpectra of Dr. Darwin, which ſtill further corroborates the doctrine of three primogenial

primogenial colours. Place a piece of coloured ſilk, about an inch in diameter, on a ſheet of white paper, about half a yard from your eyes; look ſteadily upon it for a minute; then remove your eyes upon another part of the white paper, and a ſpectrum will be ſeen of the form of the ſilk thus inſpected, but of a different colour, thus

Red ſilk produced		a green ſpectrum,
Green	-	red,
Orange	-	blue,
Blue	-	orange,
Yellow	-	violet,
Violet	-	yellow.

The reaſon of theſe phænomena is very ingeniouſly aſſigned by Dr. Darwin; he ſays, that the retina being excited into a violent and long continued action by the red rays, in the firſt experiment, at length is ſo fatigued as to become inſenſible to them; but that it ſtill remains ſenſible, that is, liable to be excited into action by any other colours at the ſame time; and therefore the ſpectrum aſſumes a green appearance, becauſe if all the red rays be taken out of the ſolar light, the remaining rays will compoſe green. See Phil. Tranſ. Vol. LXXVI. Converſely, a green object produces a red ocular ſpectrum. Now we may obſerve, that if all the green rays be taken out of the ſolar ſpectrum of ſeven colours, the remaining colours will not compound red. If indeed green be not a primitive colour, but a compoſition of blue and yellow, then will

will the eye, in looking on a green object, be at once affected by blue and yellow rays; and therefore become inſenſible to them both; and conſequently the ſpectrum will appear red. But if green be a primitive, original colour, generated by its own peculiar green-making rays, the eye in contemplating a green object, will become inſenſible only to the green rays; and therefore the other ſix priſmatic colours, which are ſpecifically different from the green, ought to be ſenſible, and produce their proper compound effect; but this would not be the ſenſation of red. In like manner, if the object be yellow, the eye will at length become inſenſible to the yellow-making rays, and the ſpectrum will be violet. Now ſince on the hypotheſis of ſeven original colours, the orange and green are primitive, though the eye be rendered inſenſible to the yellow rays, it will not be ſo to the orange and green, which therefore, together with the red, blue, violet and indigo will produce their compound effect; but the colour reſulting from this joint action is not violet, which nevertheleſs is the colour of the ocular ſpectrum. On the other hand, if there be but three primitive colours, red, yellow and blue, when the eye is inſenſible to the yellow-making rays, the ſpectrum muſt neceſſarily be violet, which is the colour that reſults from the mixture of red and blue. If it be objected, that the eye is not only inſenſible to the unmixed yellow rays, but likewiſe to the yellow of the orange and the green, then it is admitted that orange and green are compound colours. Beſides, ſince the colour which would reſult from the mixture of red, orange, green, blue,

blue, indigo and violet is not yellow, the eye ought not to be inſenſible to this colour; and conſequently, ſince by the exemption of the yellow rays from the white ſolar light, that colour does not reſult, but a diſtinct purple, it follows, that the orange and green are not primitive colours inherent in ſolar light.

It remains now only for us to ſhew, that the three colours of red, yellow and blue are adequate to the ſolution of all the phænomena of chromatics. But in order to ſhew this, few words will be ſufficient, for having ſeen, that the ſeven priſmatic colours can be generated by theſe three, it follows that all others can be generated from them, as Sir I. Newton has proved at large. However I think it will not be ſuperfluous to obſerve, that white may be directly produced by theſe three colours, without the previous generation of the other four priſmatic colours, in the ſame manner as it is uſually generated with ſeven. "I could "never yet," ſays Newton, "by mixing only two primary co- "lours, produce a perfect white. Whether it may be compoſed "of a mixture of three, taken at equal diſtances in the circum- "ference, I do not know." Now to ſhew that white may be thus generated, let an annulus of about four inches diameter be divided into three parts by lines tending towards the centre, and let theſe three diviſions be reſpectively painted red, yellow and blue, in proportions to be aſcertained by trial; then if the annulus be turned ſwiftly round its centre, it will appear white. That white may be generated by the mixture of only the three colours

colours red, yellow and blue might alſo appear from the rule which Newton himſelf has given us, for determining the colour of the compound which reſults from the mixture of any primary colours, the quantity and quality of each being given.

THE rule is this, the circumference of a circle is diſtinguiſhed into ſeven arches proportional to the ſeven muſical intervals in an octave, that is, proportional to the numbers 45, 27, 48, 60, 60, 40, 80: the firſt part is to repreſent a red colour, the ſecond orange, the third yellow, the fourth green, the fifth blue, the ſixth indigo, and the ſeventh violet. Theſe are to be conſidered to be all the colours of uncompounded light gradually paſſing into one another, as they do when made by priſms, the circumference repreſenting the whole ſeries of colours from one end of the ſun's coloured image to the other. Round the centers of gravity of theſe arches let circles proportional to the number of rays of each colour in the given mixture be deſcribed. Find the common centre of gravity of all theſe circles, and if this common centre of gravity coincide with the centre of the circle, Newton ſays that the compound will be white. Join therefore the centers of gravity of the blue and yellow circles, and from the centre of the red circle draw a right line through the centre of the principal circle; from the conſtruction it will cut the line which joins the centers of the blue and yellow circles; if therefore the number of the blue and yellow rays be to each other inverſely as their diſtances from the point where the line which joins their centers is cut by the line drawn from the centre

centre of the red circle; and if the number of red rays be to the ſum of the yellow and blue rays inverſely as the diſtances of the centre of the red circle, and the common centre of the yellow and blue from the centre of the principal circle, the common centre of gravity of the red, blue and yellow circles will coincide with the centre of the principal circle, and therefore the reſulting compound will be white.

But it is manifeſt that this conſtruction cannot be relied on, becauſe the quantities of the rays of any given colour in ſolar light, do not appear to be proportional to the ſpaces which they occupy in the rectilineal ſides of the ſpectrum. Thus it is known that the yellow making rays are predominant in ſolar light, yet the ſpace they occupy in the ſpectrum is to the ſpace occupied either by green or blue as four to five, and to the ſpace occupied by the violet only as three to five.